Low Temperature Physics and Ultra-low Temperature Physics Laboratory Group(Annual Report)

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Low Temperature Physics

and

Ultra-low Temperature Physics Laboratory Group

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Research Activities

(I) Nuclear Refrigeration (Entire Staff)

Construction of the basic facilities for the Ultra-low temperature Physics Laboratory has been completed and efforts are now being concentrated on completion of a powerful nuclear refrigerator. The cryostat including a dilution refrigerator has been mounted on an anti-vibration mount, and vacuum and helium gas circulation systems have been constructed and checked. A superconducting magnet with an inner diameter of about 9 cm has been installed. The magnet generates a field of 6 $\sim$ 8.5 T over a length of 25 cm. A field compensation winding is attached which provides an experimental space 50 cm in

length with fields below 30 G.

For the nuclear stage, a copper bundle made from 0.5 mmΦ wires is being prepared. The bundle will be 5 cm in diameter and will contain about 25 moles of copper. The refrigerator is planned to be completed by September, 1982.

(II) Studies of Refrigerators where ^{4}He is Circulated

(a) Superfluid ^{4}He Refrigerator (Vortex Cooler) (T. Satoh and T. Sato)

Studies were made on the thermal effect which occurs when superfluid HeII is forced to flow through a system. This so called vortex cooler consists of a superleak, chamber and capillary in series. By varying the mass flow velocity in the capillary, it is found that there is a rather sharp transition in the behavior of the thermal effect. This feature becomes much clearer when the experiment is performed with ^{3}He impurities added. Estimation of the Reynolds' number suggests that this transition corresponds to the classical laminar-turbulent transition in the capillary. This turbulent state is essential for the cooling effect in this device. In order to obtain further insight into the phenomena occurring in this system, we are measuring both the temperature and pressure distributions along the capillary. With ^{3}He impurities added we found a dilution cooling effect due to the mutual friction between ^{3}He atoms and the superfluid component.

(b) ^{4}He-circulating Dilution Refrigerator (^{4}He-D.R.)
(T. Satoh, N. Satoh, N. Sato, M. Okuyama and T. Ohtsuka)

We have investigated a dilution refrigerator where superfluid ^{4}He is circulated. This is known as the Leiden dilution refrigerator. It is found that the cooling behavior of the machine changes abruptly when the ^{4}He-circulating rate ($\dot{n}_4$) exceeds a certain critical value ($\dot{n}_{4c}$). In the circulation rate region above this critical value, a minimum temperature of 3.4 mK has been attained. This is the lowest temperature ever-reached with the ^{4}He-circulating dilution refrigerator. The temperature distribution along the counterflow tube also shows a drastic change at this critical circulation rate.

In the region of $\dot{n}_4 > \dot{n}_{4c}$, the temperature distribution can be fitted very well with the theoretical expression obtained with the assumption of completely ideal heat exchange in the counterflow tube. In the region of $\dot{n}_4 < \dot{n}_{4c}$, there is a broad temperature miximum at around the place 6 cm below the mixing chamber. All the facts mentioned above suggest that the pattern of the counterflow of the two phases in the counterflow tube undergoes an abrupt change at $\dot{n}_{4c}$. Although we do not as yet know the nature of the change occurring at $\dot{n}_{4c}$, our findings provide a promising feature for further development of the ^{4}He-circulating dilution refrigerator. In order to measure the flow velocity in the counterflow tube, we have been developing a pulse NMR technique. This method will be useful to investigate the change of the nature of the flow of $\dot{n}_{4c}$

(III) Valence Fluctuating Rare Earth Compounds

(T. Satoh, H. Yashima, H. Mori, N. Sato and T. Ohtsuka)

Measurements of the specific heat and the magnetic susceptibility on $CeSi_x$ ($1.55 \leq x \leq 2.00$) revealed a nonmagnetic-magnetic transition at around $x = 1.85$. For the magnetically ordered system ($x \leq 1.80$), magnetization measurements were also made. We observed a reduction of the moment of Ce atom and also the reduction of the magnetic entropy. On the basis of these results, we propose a dense Kondo model to interpret our Ce-Si system. This is the first example of a ferromagnetic dense Kondo system. Even for the nonmagnetic system ($1.85 \leq x \leq 2.00$), there are several aspects which reflect the fact that the system is a dense Kondo system. The behavior of the system can be understood rather well within the framework of the paramagnon model. In order to obtain further insight into the $CeSi_x$ system, high field magnetization and also experiments on samples diluted with La are progress. With the nuclear refrigerator apparatus, we are planning to study the Fermi-liquid behavior of the nonmagnetic system down to sub-milli degree.

(IV) High Temperature SQUID System (T. Fujita, S. Ikegawa and T. Ohtsuka)

Planar rf SQUIDs with variable thickness bridges have been fabricated from high-T_c Nb_3Ge films deposited on sapphire substrates and their performance has been tested at a bias frequency of 19 MHz. Some of the devices tested were found to operate at temperatures as high as 18 K. The noise properties were investigated by measuring the step slope parameter in the rf I-V characteristics as well as the fluctuation in output signals. The data indicate that the intrinsic device noise is as low as 10^{-4} $\Phi_o/\sqrt{Hz}$ at the optimum temperature and compares well with the theoretical expectation assuming a sinusoidal current-phase relation for the weak link. For the operation of the high Tc SQUIDs without liquid helium, a small Stirling cycle refrigerator is being constructed now. We acknowledge the collaboration of Dr. M. Suzuki and Prof. T. Anayama (Department of Electrical Engineering, Faculty of Engineering) in SQUID fabrication.

(V) On the Possibility of Superconductivity of Pd-Ag Alloys
(K. Isshiki*, T. Fujita and T. Ohtsuka)

Recently, Gyorffy et al. predicted that Pd_xAg_{1-x} alloys with $0.6 \leq x \leq 0.8$ will be superconducting with transition temperatures $0.01 \leq Tc \leq 0.5$ K. However, no experimental evidences have been observed. To re-examine the prediction, we measured the specific heat and magnetic susceptibility for several alloy samples and point-contact spectrum for a pure Pd sample. Analysis of the data obtained suggests that the electron-phonon coupling is appreciably weaker than it was believed to be and therefore superconductivity cannot be expected in the system at least above 1 mK.

(VI) Effect of Magnetic Scattering on Transport Properties in Some Films
(K. Hatanaka, S. Ikegawa, T. Fujita and T. Ohtsuka)

Both normal and superconducting tunnel junctions were prepared using monolayer barriers of various stearates with controlled magnetic impurities.

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I-V characteristics were measured to investigate the effect of magnetic scattering in the junction.

We also tried to prepare thin films of Chevrel compound $HoMo_6S_8$ by rf sputtering technique. The purpose is to investigate the possible coexistence of ferromagnetism and superconductivity by means of tunneling and other measurements.

The experiments are in the preliminary stage and being continued.

(VII) Antiferromagnetic Ordering of Enhanced Nuclear Spin in $Cs_2NaHoCl_6$

(Y. Masuda, H. Suzuki, M. Miyamoto and T. Ohtsuka)

The field dependence of the magnetic susceptibility at low temperature was investigated in a single crystal of $Cs_2NaHoCl_6$. The result was well explained by the second order Zeeman splitting of the electronic ground state with a "non magnetic" Γ_3 doublet.

Enhanced nuclear cooling experiments were carried out. Antiferromagnetic ordering of the enhanced nuclear spin system was observed at about 1.5 mK.

(VIII) Enhanced Nuclear Refrigeration of Liquid ^3He

(M. Miyamoto, H. Suzuki, Y. Masuda and T. Ohtsuka)

Our previous experiments on hfs enhanced nuclear cooling of $TmVO_4$ indicate the possibility of using $TmVO_4$ as a cooling agent to cool liquid ^3He down to submilli-kelvin temperatures. $TmVO_4$ pills have been prepared and a cooling cell is under construction.

Publications

1) H. Yashima, T. Satoh, H. Mori, D. Watanabe and T. Ohtsuka; Thermal and Magnetic Properties and Crystal Structures of $CeGe_2$ and $CeSi_2$, Solid State Communications, 41 (1982) 1.

2) H. Yashima and T. Satoh; Nonmagnetic-Magnetic Transition in Ce-Si System, Ibid., 41 (1982) 723.

3) T. Kasuya, K. Takegahara, Y. Aoki K. Hanzawa, M. Kasaya, S. Kunii, T. Fujita, N. Satoh, H. Kimura, T. Komatsubara, T. Furuno and

J. Rossat-Mignod; Anomalous Properties of Valence Fluctuating CeB_6 and CmB_6, "Valence Fluctuation in Solids", edited by L. M. Falicov, W. Hanke, M. B. Maple (North Holland Publishing Company, 1981) p.215.

4) M. Kasaya, H. Kimura, Y. Ishikawa, T. Fujita and T. Kasuya; Valence Instabilities and Electrical Properties of the La- and Y-substituted SmB_6, Ibid., p.251.

5) A. L. Allsop, B. Bleaney, G. J. Bowden, N. Nambudripad, N. J. Stone and H. Suzuki; A Nuclear Orientation Study of the Van Vleck Enhanced Nuclear Antiferromagnet Holmium Vanadate, Hyperfine Interaction 10 (1981) p849.

6) H. Suzuki, T. Inoue and T. Ohtsuka; Enhanced Nuclear Cooling and Spin-Lattice Relaxation Time in $TmVO_4$ and $TmPO_4$, Physica 107B (1981) p563.

Doctor Thesis

1. Hideo Yashima: Studies of the Valence-Fluctuating Ce-Si System.

Master Thesis

1. K. Isshiki: Possibility of Superconductivity in Pd-Ag Alloys.